IN-STEP INFLATABLE ANTENNA DESCRIPTION

Mr. Gordon Veal
Experiment Project Engineer
L'Garde, Inc.
Tustin, CA

Mr. Robert Freeland
JPL Manager, IN-STEP Inflatable Antenna Experiment
Jet Propulsion Laboratory
Pasadena, CA

Abstract

Large size space deployable antenna structures are needed for a variety of applications. Current resources limitations within the antenna user community have resulted in the need for low cost, light weight and mechanically reliable space structures. An inflatable deployable antenna concept, under development at L'Garde has such great potential for satisfying these requirements; it was selected for a NASA sponsored In-Space Technology Experiment Program (IN-STEP) flight experiment.

The objectives of the experiment are to verify low cost and light weight by building a 14 meter-diameter reflector antenna structure and demonstrate deployment reliability and reflector surface precision in a realistic operational environment. The approach will utilize the Space Transportation System (STS) launched recoverable Spartan spacecraft as the experiment carrier.

The basic experiment subsystems and their functions include (a) the inflatable structure that consists of: a thin membrane reflector structure and clear canopy structure that are joined at their perimeter to form a lenticular structure; a torus structure that supports the lenticular structure and; three strut structures that interface the torus with the experiment bus structure, (b) the canister structure that interfaces the experiment with the Spartan and is the load carrying structure for all of the subsystems, (c) the surface measurement system that remotely characterizes the reflector precision as a function of sun angle and internal pressure, (d) the inflation system that senses and controls the gas flow for deployment and pressurization and (e) the electronics that control power, functional sequences and data recording.

This paper describes the fmal hardware developed for the experiment. References in the paper identify publications covering the experiment justification and technical approach.

1. Introduction

Recent restriction on the resources available in the applications of large size space deployable antennas has resulted in the evolution of very stringent user criteria. The primary issue is cost. Others are mechanical deployment reliability, weight, mechanical packaging efficiency, aperture precision and others. This situation is not just true for the science community, but also for the commercial sector and the DoD. Current technology limitations for these classes of space structures has resulted in need for new and innovative approaches for meeting user criteria. Fortunately, a new class of space deployable structures concepts has emerged that have tremendous potential for satisfying user requirements and the new NASA theme for better, faster and cheaper. This class of structures is called inflatable space deployable. As a consequence of the high potential payoff of this concept for the user community, the L'Garde, Inc. inflatable antenna concept has been selected by NASA for an In-Space Technology Experiment Program (IN-STEP) flight experiment. The experiment is currently in the last phase of hardware development and is currently manifested to fly on STS 77 in April 1996. The purpose of this paper is to describe the final hardware developed for the experiment. Previous papers[1,2] overview the experiment and discuss and identify the potential antenna users and their application criteria. Subsequent papers are expected to address the system functional requirements and how they are reduced to the detail subsystems design drivers.

2. Experiment Objectives and Approach

The objectives of this experiment are intended to specifically address the antenna user applications criteria. Consequently, the specific objectives are to (a) validate the deployment of a 14-meter-diameter, inflatable deployable offset parabolic reflector antenna structure in a zero-gravity environment, (b) measure the reflector surface precision, which is expected to be on the order of l-mm rms, for several different sun angles and inflation pressures in a realistic thermal environment, and (c) demonstrate that a large size flight quality structure can be built for a low cost and that it can be stowed in a very small size container.

The technical approach for the experiment (Fig. 1) will be to use the Spartan recoverable spacecraft as the carrier. The Spartan services include (a) a mounting platform for the IAE, (b) power, (c) data recording, (d) attitude control, (e) electrical initiation of the experiment and (f) separation of the antenna from the carrier at the completion of the single orbit experiment.

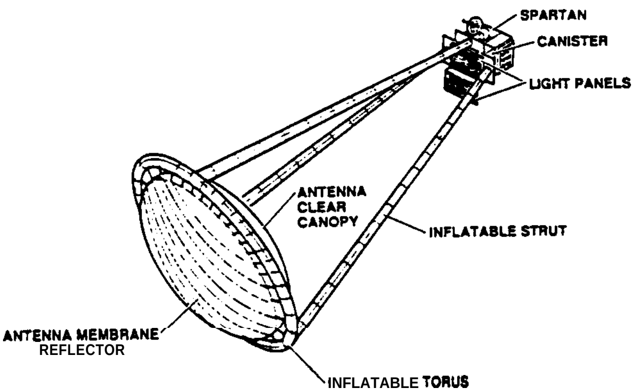

Fig. 1. Experimental Orbital Configuration

Orbital Operational Scenario

The orbital sequence for the experiment starts with the Spartan being placed overboard by the STS Remote Manipulator System (RMS). Once the orbiter has moved a safe distance away and the Spartan has been stabilized by its attitude control system, a start command from the Spartan of the experiment controller initiates implementation at the experiment. Antenna deployment commences with the opening of the canister doors and the spring-loaded ejection plate pushes the stowed inflatable structure from the canister. The inflation system then provides the nitrogen gas to the inflatable structure. Once deployed, measurement of the surface precision will be made. Because of the high drag of the fourteen meter structure causing separation of the Spartan from the STS, only one orbit will be used to implement the experiment. At that time the IAE will be separated from the Spartan, which will be retrieved, with the experiment data, by the STS.

3. Experiment System Description

The experiment system is based on five subsystems that include (a) the inflatable structure whose elements are the reflector and its canopy, the torus, which is the support structure for the reflector and the three struts that interface the torus with the canister, (b) the canister which interfaces the IAE with the Spartan and is the load carrying structures for the experiment, (c) the surface measurement system for the reflector, (d) the inflation system for all elements of the inflatable structure, and (e) the electronics that provide power, functional control and data recording for the IAE.

Inflatable Structure Subsystem

The inflatable, Figure 2, is comprised of two basic structures – the inflatable reflector assembly and the torus/strut supporting structure. The reflector assembly forms a 14 meter off-axis parabolic aperture with an f/d of 0.5. The surface accuracy goal is 1.0 mm rms as compared to a best fit parabola The reflector film, 1/4 mil aluminized mylar, is stressed to approximately 1200 psi by the inflation pressure of 3 x10^{-4} psi. This stress level is sufficiently high to assure a good reflective surface for the accuracy measurement system. The canopy is also constructed of 1/4 mil mylar but is left clear. The torus/strut structure locates the reflector assembly at the effective center of curvature of the reflector parabola as required for operation of the Surface Accuracy Measurement Subsystem. The torus also provides the rim support[3] for the reflector assembly without which the reflector assembly will take a spherical shape.

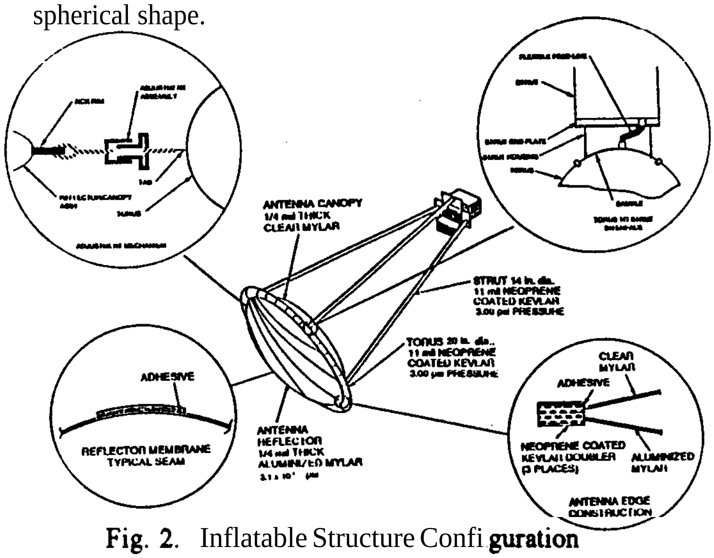

Fig. 2. Inflatable Structure Configuration

The reflector and canopy are formed by joining gores cut from flat mylar film (Fig 3), whose shape is such that the desired parabolic surface is achieved when the assembly is pressurized to the design pressure. These gores are joined using simple butt joints and adhesively attached doublers. The accuracy of the completed reflector is then measured while mounted on a fixture (Fig. 4) simulating a perfect torus structure. The reflector and canopy are then joined at their periphery by means of flexible doublers.

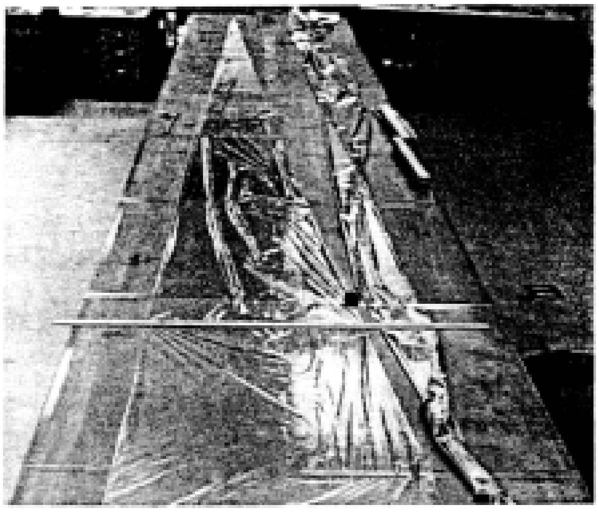

Fig. 3. Typical Flat Mylar Gore

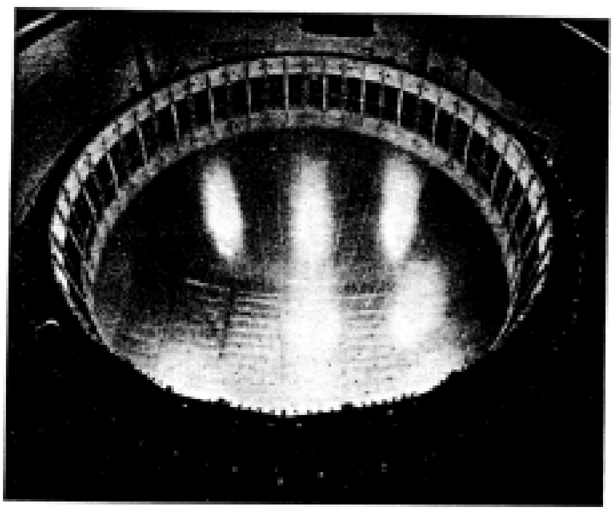

Figure 4. Reflector Mounted on Assembly Ring

The torus and struts are also constructed of gores or segments. However, in this case the material is neoprene coated Kevlar 11 mils thick (Fig.5). The torus is assembled with the aid of a large mandrel (Fig, 6) that assures the straight segments, that this ring structure is based on, are accurately joined. A typical joint during the assembly process is shown in Fig. 7. The final step in the torus assembly is to establish a reference plane, for the torus that represents a zero "g" loading condition for attachment of the reflector assembly. This is accomplished by submerging the torus in a large trough in a neutrally buoyant condition. This allows the torus to assume an unstressed configuration. The torus is shown in Fig. 8 mounted on the trough prior to alignment. The struts are each formed from two segments of neoprene coated Kevlar. Again, simple butt joints are used. A full scale engineering model strut is shown in Fig. 9 with the multi-layer insulation installed.

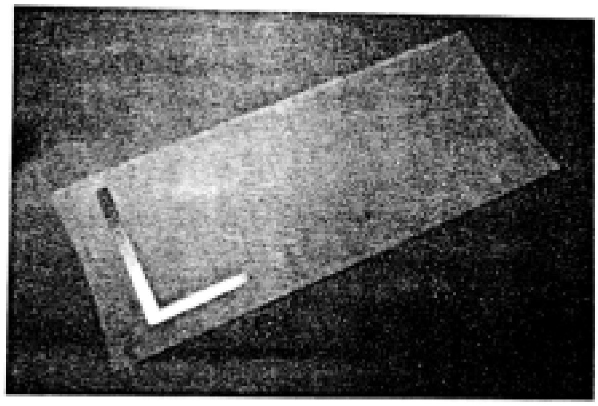

Fig. 5. Torus Gore

Fig 6 Torus Mandrel

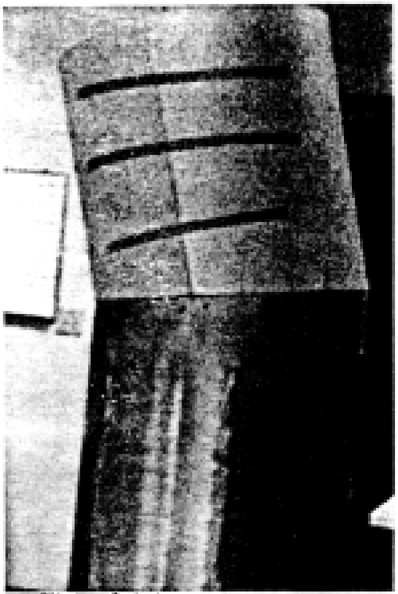

Fig 7 Joining Torus Gores

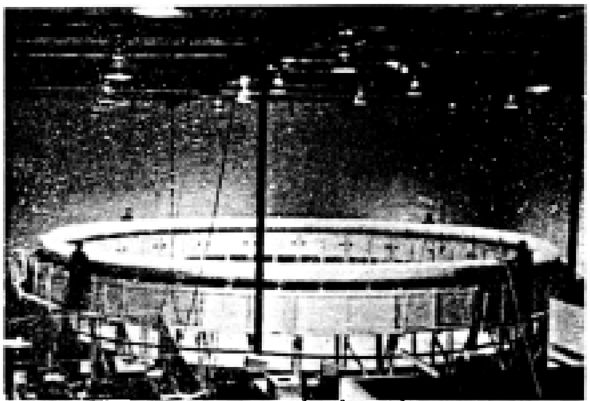

Fig. 8. Torus Ready for Alignment

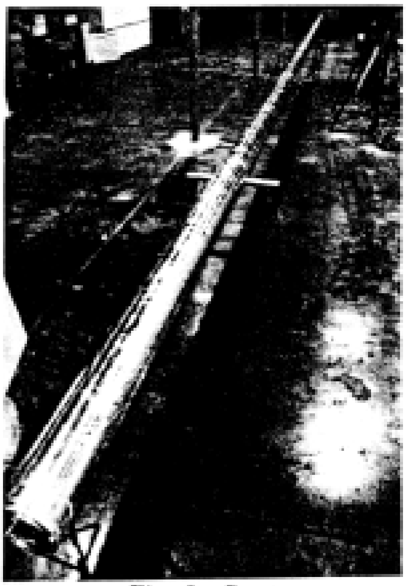

Fig. 9. Strut

Canister Structure Subsystem

The canister is the primary structure for the experiment. It contains all experiment components, provides the structural interface with the Spartan carrier vehicle, provides doors that open to allow the inflatable to deploy, ejects the stowed inflatable at the beginning of the deployment sequence, and accommodates its own jettison with the inflatable structure from the Spartan after the experiment is completed. The basic dimensions of the canister are 80 inches long, 43 inches wide and 21 inches high. The general canister arrangement is shown in Fig. 10.

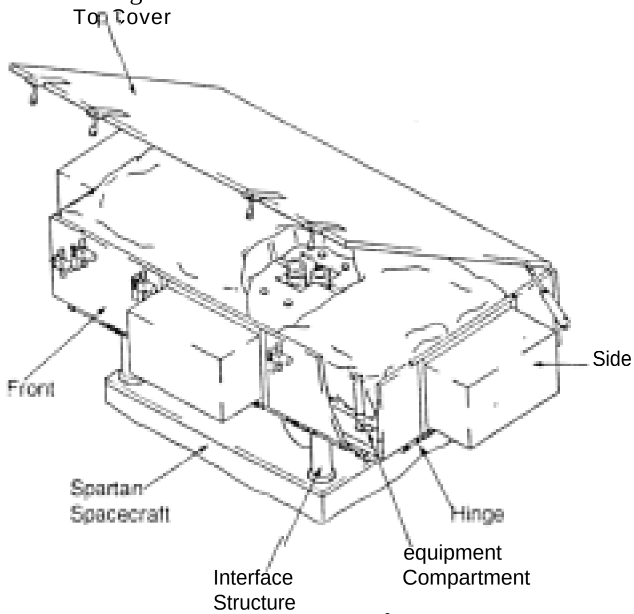

Fig. 10. Canister Configuration

The canister is constructed of a machined aluminum base plate and aluminum honeycomb doors (Fig. 11). The “pods” on the three side doors contain the packaged struts and the strut/canister interface attachment. The latch system (Fig. 12) that holds the top cover in position is released by firing the redundant NSI initiators. Kick off spring assemblies assure initial door motion. Torsion springs at the door hinge line provide the primary door articulation force. The door opening velocity and final position are controlled by a silicon fluid filled damper (Fig. 13).

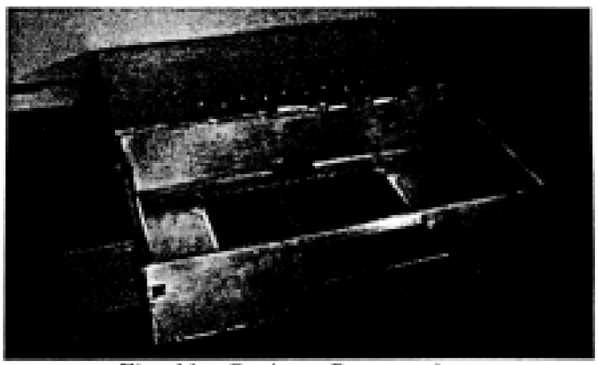

Fig. 11. Canister Construction

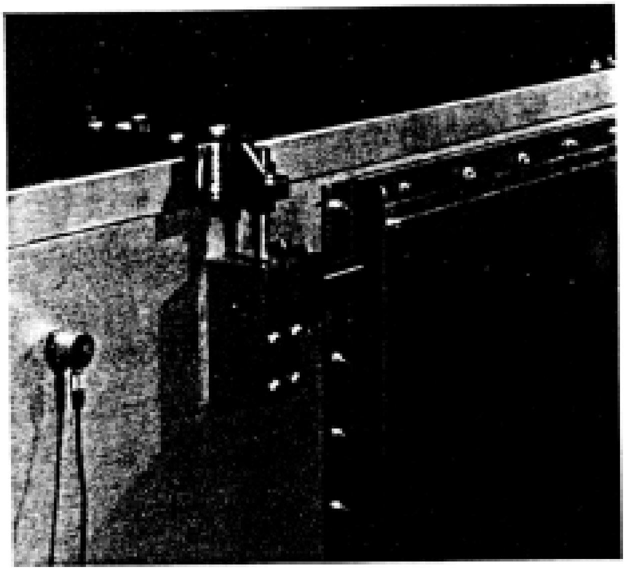

Fig. 12. Top Cover Latch

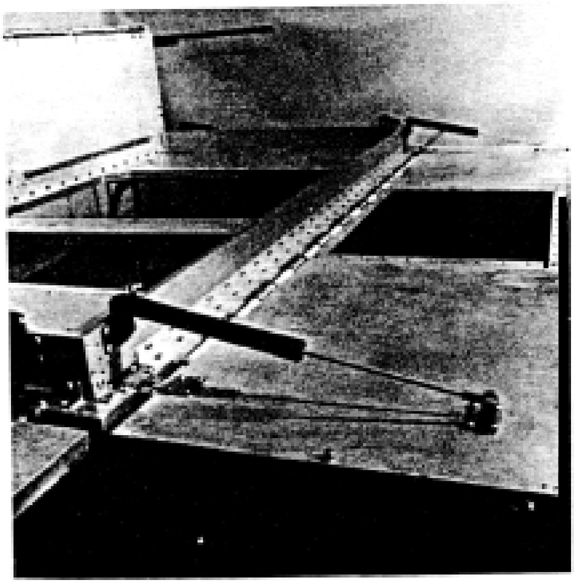

Fig. 13. Door Torsion Springs and Damper

The inflatable structure ejector system consists of a push plate, guide rod and four spring pushers (Fig. 14). The spring system is designed to provide an ejection velocity to the inflatable of 1½ meters/sec and is released by a pin puller identical to those used to release the top cover.

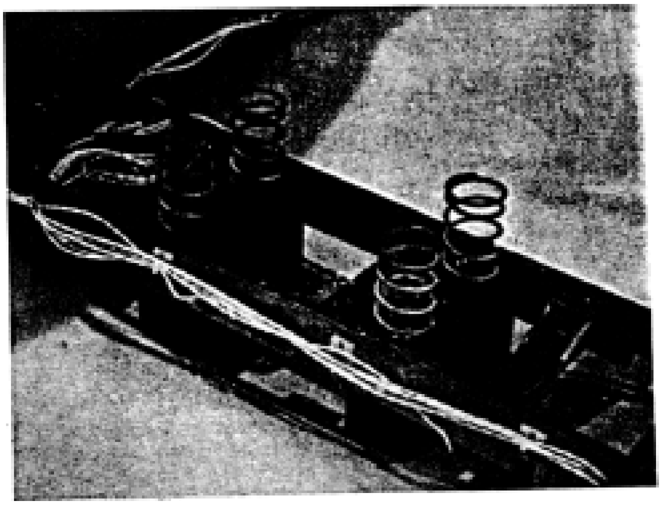

Fig. 14. Ejector Spring Pack

Surface Accuracy Measurement Subsystem (SAMS)

A basic objective of the experiment is to measure the accuracy of the reflector surface under varying orbital conditions. The method selected is based on the Digital Imaging Radiometer first developed by MDAC[4,5,6]. The system was extensively modified to reduce its size, adapt it for space. applications and increase the measurement speed. The system is shown functionally in Fig. 15.

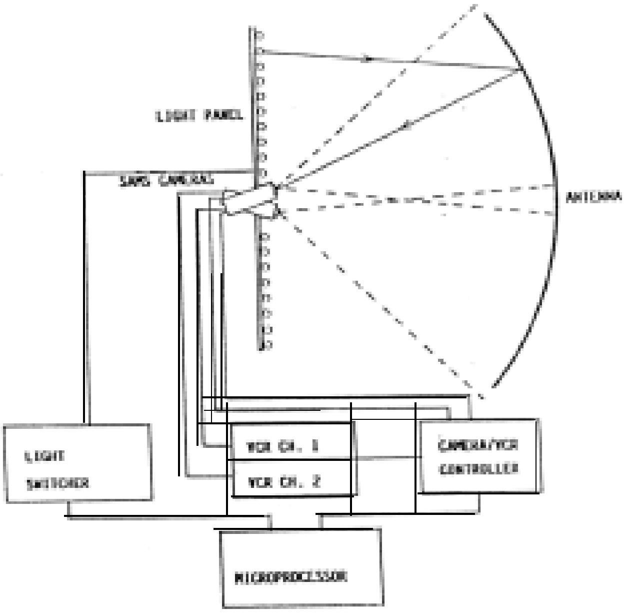

Fig. 15. Surface Accuracy Subsystem Functional Diagram

The system operates on the principle of reflection. A light source mounted on a plane at the effective center of curvature is used to illuminate the parabolic surface to be measured. The reflected light and its location on the surface is recorded by a camera located at the effective radius of curvature. Given the location of the camera, the light source and the reflection, the slope of the surface at the reflection can be calculated. If sufficient light sources (in this case 512) are provided the slope at many points can be calculated. These slopes are then integrated to provide a complete map of the surface. Measurement time for a single mapping is only forty seconds. This will result in over one hundred complete mappings during the experiment.

The video cassette recorder is a three deck system Model V83 manufactured by TEAC. This unit, shown in Fig. 16, is based on the well proven single deck concept. The video camera selected for this application is a high resolution CCD camera supplied by Videospection (Fig. 17). The light panel is designed and fabricated by L'Garde and is shown in Fig. 18. It is a combination of 8 printed circuit boards that support the LED clusters that form each of the light sources. In addition, a portion of the light panel control electronics are also mounted on the circuit cards in order to minimize the amount of interconnect wiring between the light panels and the electronics control unit.

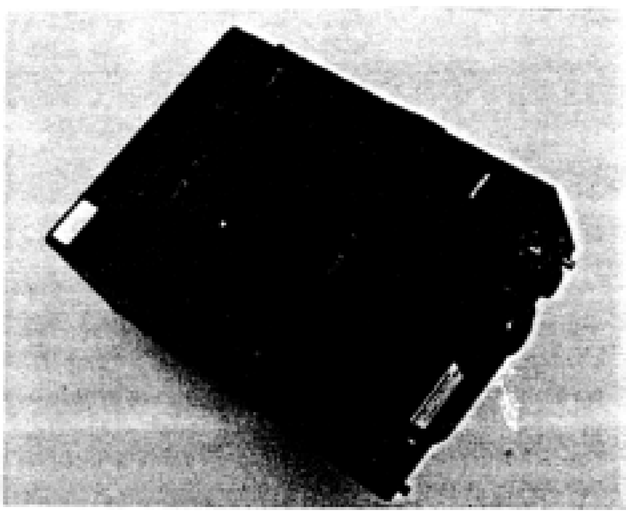

Fig. 16. VCR

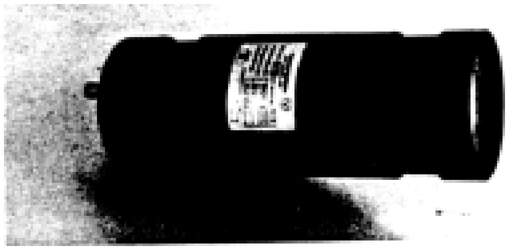

Fig. 17. Video Camera

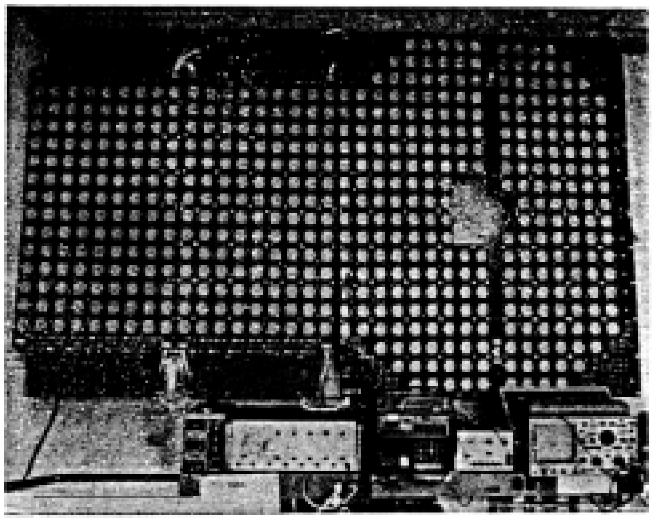

Fig. 18. SAMS Light Panel Assembly

Inflation Subsvstem

The inflation subsystem stores the nitrogen gas used to inflate the torus/struts and the reflector assembly. It also provides the pressure regulation and control valves to maintain the torus/struts at 3 psi and the reflector at 3.1 x 10^{-4} psi. A schematic of the system is shown in Fig. 19. The majority of the components, such as the pressure vessels, enable valve, pressure regulators, pressure transducers, control valves, and filters are the same as those used for the Spartan attitude control system. The fully assembled and functional engineering test system is shown in Fig. 20. The honeycomb panel that supports the inflation system components also supports the video cameras and electronic boxes. It is rigidly attached to the Spartan upper deck and is recovered with the carrier vehicle.

The low pressure transducers, tubing and fittings downstream of the inflation subsystem control valve are jettisoned with the inflatable structure and canister.

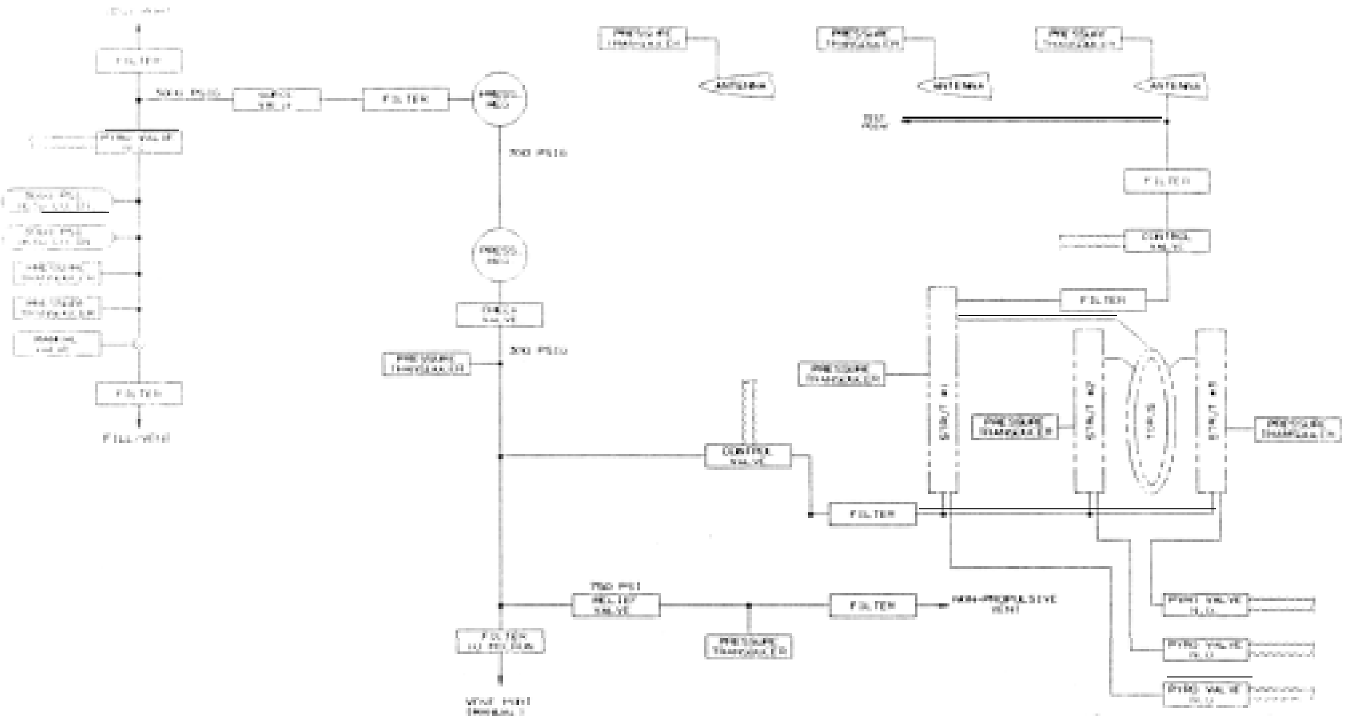

Fig. 19. Inflation Subsystem Schematic

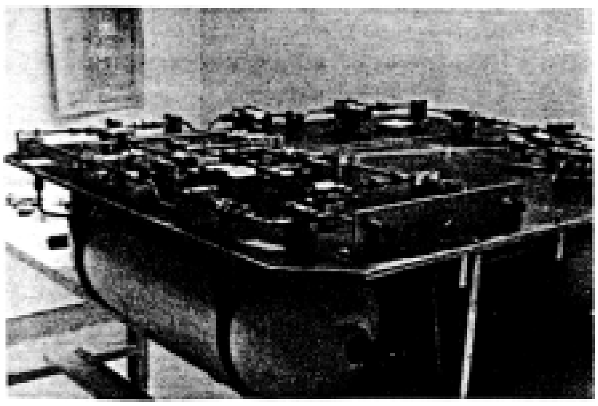

Fig. 20. Inflation Subsystem

<u>Electronics Subsvstem</u>

The IAE electronics (Fig. 21) consist of the following major components:

- Microcomputer
- Analog data acquisition system
- Digital data link to Spartan
- Squib fire and solenoid control

There are no command or control links between the IAE and the Spartan, so the entire experiment must run autonomously in the IAE. A microcomputer provides the necessary local control. It sequences the experiment deployment, operates the cameras and VCRs, regulates the inflatable pressures and inflation rates, and sequences the light panels.

The microcomputer is a single-chip 16-bit CMOS design that has >8K bytes of program ROM and >200 bytes of program RAM. The microcomputer also contains timers, interrupt controllers, serial interface, and analog to digital converter. The control program (contained in ROM) is multitasking and simultaneously runs the experiment and in the background reads the status of the VCRs, maintains a real-time clock, and generates data for the Spartan's recorder.

There are up to 48 channels of analog signals that are sampled by the analog data acquisition system. These channels sense 9 pressure sensors, 19 temperature sensors, 5 position sensors and a handful of other devices. The system consists of three analog signal conditioner boards that filter, amplify and select one of 16 analog channels at a time. These signals are then re-selected and converted to digital data in the microcomputer.

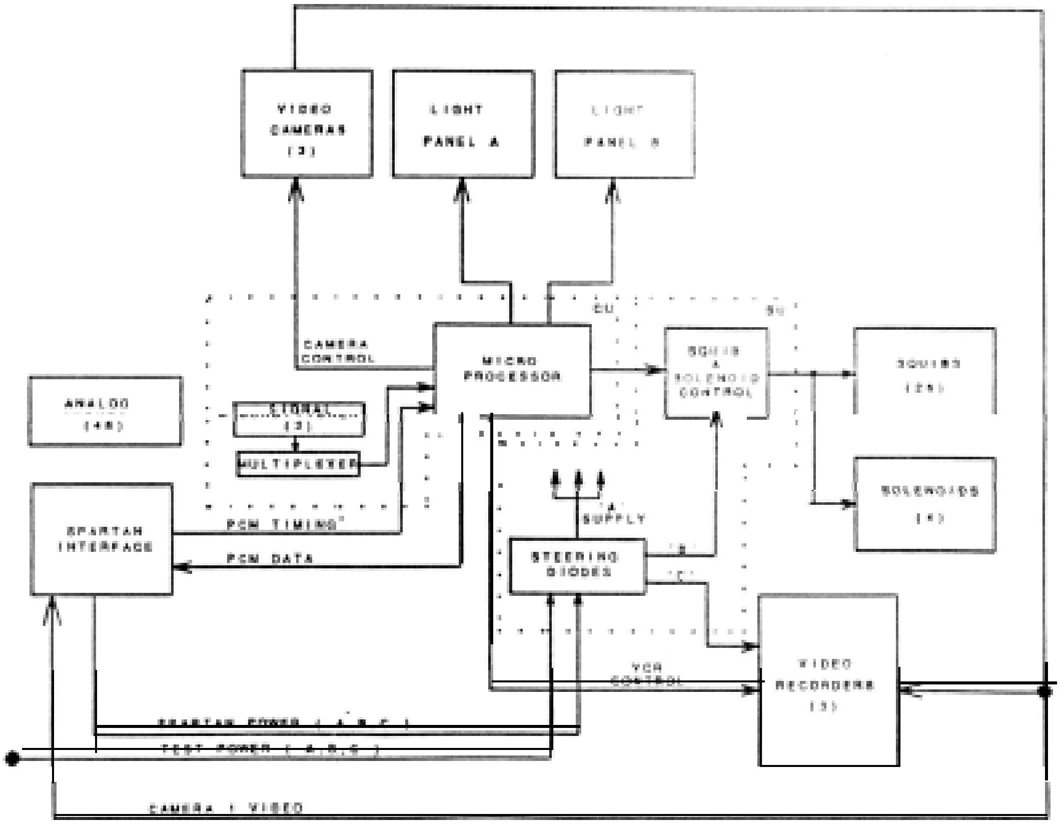

Fig. 2 1. Functional Block Diagram

The digital data link to Spartan operates at 12,500 bits per second. It is divided into sixteen channels, of which the IAE occupies two channels. In these two channels, 64 ten-bit parameters are continuously recorded by the microcomputer to the Spartan digital recorder. Most of these parameters are digital copies of the values sensed by the analog data acquisition system. Other things recorded are the status of the VCR, intensity of the light panels and the selected gain of the video cameras.

The squib fire and solenoid control circuitry can control up to 28 squib devices and four solenoids. This subsystem consists of four identical boards each of which handle seven squibs and one solenoid. The circuitry also contains continuity sensing devices for all the squibs. This box is interfaced to the microcomputer via two serial interfaces. One interface carries firing and valve opening commands to the switching unit. The other interface carries squib continuity data back to the microcomputer.

These circuits are contained on two sets of circuit boards (Fig. 22) and packaged in two identical aluminum housings (Fig. 23).

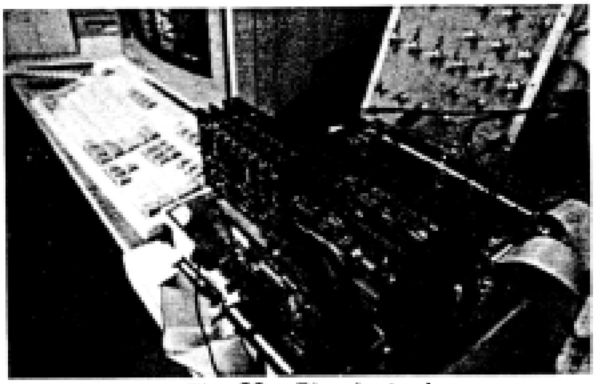

Fig. 22. Circuit Cards

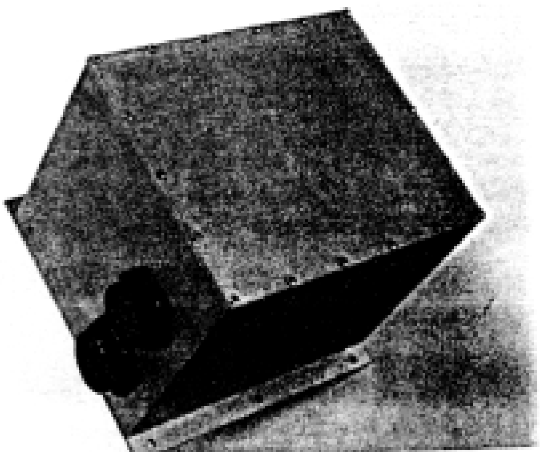

Fig. 23. Assembly

4. Program Status

The experiment is scheduled to fly on STS 77 in April of 1996. At this time, the experiment flight hardware is in the fmal stages of assembly and acceptance test and is scheduled for the delivery to Goddard Space Flight Center in late November 1995 for integration with the Spartan carrier vehicle.

5. Conclusions

Results of this experiment to date have demonstrated that inflatable technology can be used to construct large deployable antennas that are light weight, packageable into small volumes and are inexpensive. The upcoming flight will demonstrate on-orbit deployment and surface accuracy.

Acknowledgements

The research and development described in this paper was carried out at L'Garde, Inc. under contract to the Jet Propulsion Laboratory, Califomia Institute of Technology and Sponsored by the National Aeronautics and Space Administration.

The authors would like to acknowledge the following individuals for their contribution to the development of the experiment; A.B. Chmielewski and S. Prusha of JPL for providing an effective interface with the NASA sponsor; D. Carson and M. Steiner of the Spartan Project Office at the NASA GSFC for the development of a Spartan carrier configuration to accommodate the experiment; G. Bilyeu and S. Dalbey of L'Garde, experiment Program Management and A. Palisoc, M. Thomas, T. Daggett, C. Cassapakis and P. Malone of L'Garde for the experiment development.

References

1. Freeland, R.E., Bilyeu, G., "IN-STEP Inflatable Antenna Experiment," presented at the 43rd Congress of the International Astronautical Federation, Washington, D.C., 1992.

2. Freeland, R.E., Bilyeu, G., Veal, G.R., "Validation of a Unique Concept for a Low-Cost, Lightweight Space-Deployable Antenna Structure," presented at the 44th Congress of the International Astronautical Federation, Graz, Austria, Oct. 1993.

3. Grossman, G. ***Analysis of Loads in Rim Support of Off-Axis Inflatable Reflector,*** L'Garde Technical Report, LTR-87-GG-041, Dec. 1987.

4. Blackmon, J., "Development and Performance of a Digital Image Radiometer for Heliostat Evaluation at Solar One,' ***Proc. of the ASME Solar Engineering Division Sixth annual Conference***, Las Vegas, NV, Apr. 8-12, 1984.

5. Blackmon, J, et al., "Design and Performance of a Digital Image Radiometer for Dish Concentrator Evaluation," ***Solar Engineering 1987,*** Goswami, Watanabe, and Healy, editors, ASME, NY, pp. 318-323, vol. 1, 1987.

6. Palisoc, A., "PANT Analysis of 28 m Reflector for LINX," L'Garde Memo, LM-91-AP-143, June 1991.